ENGINEERING EXPERIMENT STATION

Georgia Institute of Technology

PROJECT INITIATION

Date October 26, 1956

PROJECT TITLE: The Effect of Fluoro Substitutes on Reactivity and Reaction Mechanisms

PROJECT NO: B-115

PROJECT DIRECTOR: Jack Hine

SPONSOR: Atomic Energy Commission

EFFECTIVE: September 15, 1956 ESTIMATED TO RUN UNTIL: September 14, 1957

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PROJECT NO: B-115

PROJECT DIRECTOR: Jack Hine

SPONSOR: Atomic Energy Commission

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B-115

ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 1

PROJECT NO. B-115

THE EFFECT OF FLUORO SUBSTITUENTS ON REACTIVITY AND REACTION MECHANISMS

By

JACK HINE, ROBERT G. GHIRARDELLI and ARTHUR D. KETLEY

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ATOMIC ENERGY COMMISSION
CONTRACT NO. AT-(40-1)-2084

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I. INTRODUCTION

As stated in our original proposal we hoped to begin work on this contract in September, 1956. Since we were not informed that the contract was to be made until around September 15, 1956 this was not possible. Therefore, in order to accomplish one man-year of work by the September, 1957 expiration date we employed Dr. Robert G. Ghirardelli, who started work in February, 1957 and Dr. Arthur D. Ketley, who started in March, 1957. Dr. Ghirardelli received his Ph.D. from the California Institute of Technology and Dr. Ketley graduated from University College, London, England.

II. SUMMARY OF RESULTS

Dr. Ghirardelli has undertaken a study of the effect of β-fluorine substituents on reactivity by the S_N2 mechanism. Earlier work had already shown that one β-fluorine atom decreases S_N2 reactivity.[1] If β-fluorines deactivate only by a polar effect, the deactivation observed would be expected to increase by the same amount for each successive introduction of a β-fluorine substituent. On the other hand, if steric hindrance is of importance, a second β-fluorine should produce more deactivation than the first and a third should cause a still sharper increase in deactivation. In order to use this criterion for the nature of the substituent effect, the reactivity of the series CH_3CH_2I, FCH_2CH_2I, F_2CHCH_2I, F_3CCH_2I toward sodium thiophenoxide in methanol is being studied. All of these fluoroiodides have now been prepared and/or purified. The rate constant for the reaction of F_3CCH_2I at 60° C has been found to be $(1.40 \pm 0.02) \times 10^{-4}$ l. mol^{-1} sec^{-1} while the values for F_2CHCH_2I are $(6.11 \pm 0.06) \times 10^{-3}$ at 60° C and $(7.70 \pm 0.04) \times 10^{-4}$ at 40° C. A comparison with the data relating to one β-fluorine[1] suggests that the effect of the first fluorine is almost entirely polar while that of the third fluorine is about half polar and half steric. A more definite and detailed discussion must await the kinetic data on the other two compounds to be studied.

Dr. Ghirardelli has also prepared F_3CCHI_2 for use in studies on the effect of β-fluorine on the stability of carbanions and on the effect of fluorine on reactivity in elimination reactions. In this preparation by the following reaction series[2]

$$F_3CCONH_2 \xrightarrow{LiAlH_4} F_3CCH_2NH_2 \xrightarrow[NaNO_2]{HCl} F_3CCHN_2 \xrightarrow{I_2} F_3CCHI_2$$

a small amount of a previously unreported solid by-product was obtained in addition to the liquid major product.

Dr. Ketley has been engaged in checking certain reports by Haszeldine[3] on the reactivity and reaction mechanisms of some fluorinated halomethanes. One such report was that chlorodifluoromethane is inert to the action of 15 per cent potassium hydroxide in ethanol for 24 hours at 35° C, a finding that

seemed anomalous in view of the rate constant (8×10^{-4} l. mol^{-1} sec^{-1}) that has been determined for the reaction of this haloform with alkali in aqueous solution at 25° C.[4] We find instead that chlorodifluoromethane reacts very rapidly with 15 per cent ethanolic potassium hydroxide, with the formation of a precipitate immediately and the liberation of the theoretical amount of chloride ion within a minute. It was also reported[4] that difluoroiodomethane, under similar conditions, yielded halide, carbonate and 19 per cent methylene fluoride as the only reported products. Since the formation of methylene fluoride suggests that the reaction of this compound may deviate from the path usually followed by haloforms, we reinvestigated this report. We found that fluoroform and ethyl difluoromethyl ether were the principal volatile reaction products. While a small amount of methylene fluoride appeared to have been formed, its yield was certainly less than 10 per cent and probably less than 5 per cent.

Respectfully submitted:

Jack Hine
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

III. BIBLIOGRAPHY

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2. H. Gilman and R. G. Jones, ibid., 65, 1458 (1943).
3. R. N. Haszeldine, J. Chem. Soc., 4259 (1952)
4. J. Hine and P. B. Langford, J. Am. Chem. Soc. In press.

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PROGRESS REPORT NO. 3

PROJECT NO. B-115

THE EFFECT OF FLUORO SUBSTITUENTS ON REACTIVITY AND REACTION MECHANISMS

By

JACK HINE and ROBERT WIESBOECK

ATOMIC ENERGY COMMISSION
CONTRACT NO. AT-(40-1)-2084

16 JUNE 1959

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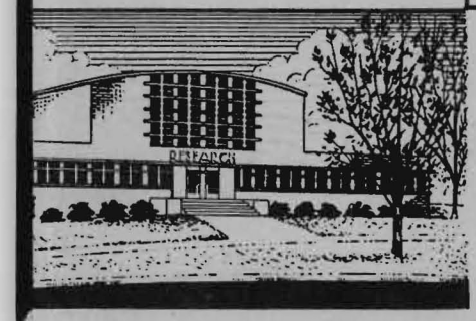

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Atlanta, Georgia

PROGRESS REPORT NO. 3

PROJECT NO. B-115

THE EFFECT OF FLUORO SUBSTITUENTS ON REACTIVITY AND REACTION MECHANISMS

By

JACK HINE and ROBERT WIESBOECK

ATOMIC ENERGY COMMISSION
CONTRACT NO. AT-(40-1)-2084

16 JUNE 1959

SUMMARY OF RESULTS

Due largely to the fact that Mr. O. B. Ramsay, who has accepted an appointment as postdoctoral research assistant on this project, has taken considerably longer to finish his Ph.D. thesis work at the University of Pennsylvania than he originally estimated, several man-months less were expended on this project than had been planned for the current year. Although we do not plan to request additional financial support for this project from the Atomic Energy Commission, we do plan to request an extension of time without additional funds to permit us to complete the work that we have planned to carry out.

During the current year our study of the effect of β-fluorine atoms on S_N2 reactivity, which was submitted as a part of last year's progress report, was published in the Journal of Organic Chemistry.[1]

The research carried out during the period of this progress report has consisted almost entirely of studies of the reactions of 1,1,1-trifluoro-2,2-dihaloethanes with bases. Second order rate constants for carbanion formation, as measured by deuterium exchange, have been obtained for four different compounds in aqueous and in methanolic solution. Reactivities were found to vary in the order $CF_3CDBr_2 > CF_3CDI_2 > CF_3CDBrCl > CF_3CDCl_2$, the effect of changing α-substituents on the reactivity being qualitatively the same as that found earlier in studies on haloforms[2], except that the diiodide was somewhat less reactive than expected. Rate constants for the destruction of sodium methoxide by reaction with these compounds (as their protium derivatives) were also determined, with the observation that the reactivities varied in the order $CF_3CHI_2 > CF_3CHBr_2 > CF_3CHBrCl > CF_3CHCl_2$.

For the latter three compounds it seems fairly well assured that the reaction being studied is practically entirely dehydrohalogenation, but it is quite possible that a dehalogenation process is important in the reaction of the diiodide. We believe that these results shed considerable light on the ease of carbanion formation from organic halides.

We plan during the remainder of our work to study the kinetics of the dehydrohalogenation of a variety of polyhaloethanes. We plan then to attempt to establish linear free energy relationships between the dehydrohalogenation rates and the structure. We hope by observing deviations from these relationships or by establishing the need for two types of such relationships to be able to demonstrate that some of the reactions are concerted processes and that others involve carbanion intermediates[3].

Respectfully submitted,

Jack Hine
Project Director

Approved:

Wyatt C. Whitley, Chief
Chemical Sciences Division

APPENDIX

1. J. Hine and R. G. Ghirardelli, J. Org. Chem., 23, 1550 (1958).

2. J. Hine, N. W. Burske, M. Hine and P. B. Langford, J. Am. Chem. Soc., 79, 1406 (1957); J. Hine, R. Butterworth and P. B. Langford, ibid, 80, 819 (1958).

3. For a discussion of the difference between the concerted and carbanion mechanisms for dehydrohalogenations see J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, see 7-1a.

FINAL REPORT

PROJECT NO. B-115

THE EFFECT OF STRUCTURE ON THE REACTIVITY OF POLYFLUORO ORGANIC COMPOUNDS

By

JACK HINE, ROBERT G. GHIRARDELLI, ROBERT WIESBOECK,
ARTHUR D. KETLEY, and O. BERTRAND RAMSAY

U. S. ATOMIC ENERGY COMMISSION
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MARCH 31, 1960

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Atlanta, Georgia

FINAL REPORT

PROJECT NO. B-115

THE EFFECT OF STRUCTURE ON THE REACTIVITY OF POLYFLUORO ORGANIC COMPOUNDS

By

JACK HINE, ROBERT G. GHIRARDELLI, ROBERT WIESBOECK,
ARTHUR D. KETLEY, and O. BERTRAND RAMSAY

U. S. ATOMIC ENERGY COMMISSION
CONTRACT NO. AT-(40-1)-2084

MARCH 31, 1960

In the study of the effect of fluoro substituents, particularly polyfluoro substituents, on reactivity and mechanisms of organic reactions, nucleophilic substitution reactions, the formation of methylenes and carbanions, and elimination reactions have been investigated.

A study of the reactions of sodium thiophenoxide with ethyl iodide, 2-fluoroethyl iodide, 2,2-difluoroethyl iodide, and 2,2,2-trifluoroethyl iodide is described in the attached reprint (Appendix No. 1). The reactivity was found to decrease almost linearly with the number of β-fluoro substituents, suggesting that the deactivation produced by such substituents is largely due to polar rather than steric factors.

The reaction of difluoroiodomethane with base appears to be initiated by a one-step transformation into the reactive intermediate, difluoromethylene. The evidence for this and further information about the formation of difluoromethylene are described in the attached manuscript (Appendix No. 2), which has been accepted for publication in the Journal of Organic Chemistry.

The kinetics of carbanion formation, as measured by base-catalyzed deuterium exchange, have been studied for 2,2-dichloro-1,1,1-trifluoroethane, 2-bromo-2-chloro-1,1,1-trifluoroethane, 2,2-dibromo-1,1,1-trifluoroethane, 2,2-diiodo-1,1,1-trifluoroethane, and 2,2-dichloro-1,1-difluoro-1-methoxyethane in aqueous and methanolic solution. This study and the information thus obtained about the effect of β-fluoro substituents on ease of carbanion formation are described in the attached manuscript (Appendix No. 3) prepared for submission to the Journal of the American Chemical Society.

The dehydrofluorination of the four 2,2-dihalo-1,1,1-trifluoroethanes whose deuterium exchange was studied was also investigated. As described in the enclosed manuscript (Appendix No. 4) these compounds are the first saturated

aliphatic halides that have yet been shown to undergo dehydrohalogenation by the unusual carbanion mechanism for elimination.

Respectfully submitted,

Jack Hine
Project Director

Wyatt C. Whitley, Chief
Chemical Sciences Division

J. E. Boyd, Director
Engineering Experiment Station

APPENDIX I

REPRINT

[Reprinted from the Journal of Organic Chemistry, **23**, 1550 (1958).]

The S_N2 Reactivity of β-Fluoroethyl Iodides[1]

JACK HINE AND ROBERT G. GHIRARDELLI

Received March 18, 1958

It has been shown earlier that β-fluorine, chlorine, and bromine substituents all decrease S_N2 reactivity,[2] at least in the reactions of ethyl bromides with sodium thiophenoxide in methanol.[3] We have now studied the effect of one, two, and three β-fluorine substituents on the reactivity of ethyl iodide under the same conditions.

EXPERIMENTAL

Reagents. Reagent ethyl iodide (Matheson, n_D^{25} 1.5098) was used as received while the 1,1-difluoro-2-iodoethane and 1,1,1-trifluoro-2-iodoethane purchased were fractionally distilled. Each of the latter compounds had been made by the Columbia Organic Chemicals Co., Columbia, S.C., by the action of sodium iodide on the appropriate *p*-toluenesulfonate.[4] For the difluoroethyl iodide, we found b.p. 86.8–87.1° (740 mm.), $n_D^{25.2}$ 1.4577, d_4^{25} 2.1840, in comparison with previous reports of b.p. 89.5°,[5] $n_D^{12.2}$ 1.46807,[5] $d_4^{12.2}$ 2.24328,[5] d_4^{20} 2.2259.[6] For the trifluoroethyl iodide, b.p. 53.5–54.0° (732 mm.), n_D^{25} 1.3981 (reported,[4] b.p. 55.0°, n_D^{25} 1.3981).

The 2-fluoroethyl iodide used was prepared from 2-fluoroethyl bromide[7] by the action of sodium iodide in acetone. A solution of 30.6 g. (0.24 mole) of 1-bromo-2-fluoroethane and 40 g. (0.29 mole) of sodium iodide in 200 ml. of acetone was refluxed for 4 hr. and then most of the acetone was removed by fractional distillation. When the residue was cool, 60 ml. of water was added, the two resultant layers were separated, and the aqueous layer was extracted with methylene chloride. This extract was combined with the organic layer and fractionated to give 2.6 g., b.p. 94.5–96.5°, 29.6 g., b.p. 96.5–97.0°, and after the addition of a still base (bromobenzene), 6.4 g., b.p. 95.8–96.5° (all at 741 mm.). The total yield was thus 92% and for the middle fraction, n_D^{25} 1.5010, d_4^{25} 2.136, molar refractivity[8] calcd. 24.24, found 24.00. Henne and Renoll report that 1-fluoro-2-iodoethane boils at 98–102° but give no other properties.[10]

The methanol and thiophenol used and the methods of preparing sodium thiophenoxide solutions and titrating for thiophenol have been described previously.[3]

Kinetic runs. The kinetic runs were carried out as described previously[3,11] except that unpainted long-necked Erlenmeyer flasks were used as reaction vessels, 5 ml. of acetic acid was added to stop the reaction and the thiophenol was then titrated in the reaction flask.

Reaction products. Some of the residual solutions from the reaction of trifluoroethyl iodide with sodium thiophenoxide were combined and the methanol removed by heating to 90°. The remaining material was then added to 20 ml. of water and 30 ml. of ether. The ether was evaporated and the residue fractionally distilled in vacuum giving principally a colorless liquid, b.p. 62–63° (5.5 mm.), n_D^{20} 1.4906, d_4^{20} 1.2582, molar refractivity[8] calcd. for $C_6H_5SCH_2CF_3$ 43.47, found 44.21. Analogous treatment of residues from the difluoroethyl iodide reaction gave a product, b.p. 87–89° (7 mm.), n_D^{20} 1.5350, d_4^{20} 1.1977, molar refractivity[8] calcd. for $C_6H_5SCH_2CHF_2$ 43.47, found 45.28.

Calculations. Rate constants were calculated for each point by use of the integrated form of the second order rate equation

$$k = \frac{2.303}{t(a-b)} \log \frac{b(a-x)}{a(b-x)}$$

where $a = [RI]_0$, $b = [C_6H_5SNa]_0$, $x = b - [C_6H_5SNa]_t$, t = time (sec.). This equation is derived with the assumption that only one halogen atom (the iodine) is replaced, in

(1) Part VIII in the series "The Effect of Halogen Atoms on the Reactivity of Other Halogen Atoms in the Same Molecule." This work was supported in part by the U. S. Atomic Energy Commission.

(2) For the meaning of the term S_N2, see J. Hine, *Physical Organic Chemistry*, McGraw-Hill Book Co., Inc., New York, N.Y., 1956, chap. 5.

(3) J. Hine and W. H. Brader, Jr., *J. Am. Chem. Soc.*, **75**, 3964 (1953).

(4) G. V. D. Tiers, H. A. Brown, and T. S. Reid, *J. Am. Chem. Soc.*, **75**, 5978 (1953).

(5) F. Swarts, *Bull. Acad. roy. Belg.*, 383 (1901); *Chem. Zentr.*, II, 804 (1901).

(6) V. Desreaux, *Bull. Soc. chim. Belg.*, **44**, 249 (1935).

(7) F. W. Hoffmann, *J. Org. Chem.*, **14**, 105 (1949).

(8) The atomic refraction constant for fluorine varies from 0.95 to 1.24.[9] We have used an average value, 1.10.

(9) *Cf.* A. V. Grosse and G. H. Cady, *Ind. Eng. Chem.*, **39**, 367 (1947).

(10) A. L. Henne and M. W. Renoll, *J. Am. Chem. Soc.*, **58**, 889 (1936).

(11) J. Hine, S. J. Ehrenson, and W. H. Brader, *J. Am Chem. Soc.*, **78**, 2282 (1956).

agreement with earlier observations[3] and the known unreactivity of alkyl fluorides. Data on a typical run are shown in Table I and in Table II are summarized all of the rate constants and average deviations obtained and also the heats and entropies of activation calculated from the equation.[12]

$$k = \frac{kT}{h} e^{-\Delta H\ddagger/RT} e^{\Delta S\ddagger/R}$$

The deviations listed on the $\Delta H\ddagger$ and $\Delta S\ddagger$ values are those obtained by using the lower temperature rate constant plus its average deviation and the higher temperature rate constant minus its average deviation.

TABLE I

REACTION OF 2,2,2-TRIFLUOROETHYL IODIDE WITH SODIUM THIOPHENOXIDE IN METHANOL AT 40.0°[a]

Time, Sec.	Iodine,[b] 0.05078M, Ml.	10^5k, L. Mole^{-1} Sec.$^{-1}$
0	17.53	
56,580	16.41	1.63
141,480	14.85	1.70
249,660	13.15	1.75
357,360	12.06	1.65
487,440	10.68	1.68
665,820	9.12	1.72
859,920	8.02	1.68
1,178,580	6.51	1.66
		Av. 1.68 ± 0.03

[a] $[CF_3CH_2I]_0 = 0.07358M$. [b] Per 30.39 ml. sample.

poses of comparison, a plot of the data on the reactivity of increasingly β-methylated ethyl bromides toward iodide ion at 25°[14] is also given in Fig. 1. The influence of the three β-methyl groups of neopentyl halides is rather generally agreed to be steric in character[15,16] and is seen in the Figure to be only slightly larger than that of three β-fluorine atoms. The curvature of the line for the β-methyl compounds is far more pronounced than that for the fluoro compounds. It thus seems likely that the effect of the fluoro atoms is largely polar. This conclusion is supported by the fact that fluorine atoms are nearer in size to hydrogen atoms than to methyl groups. The covalent radius plus the van der Waals radius for hydrogen, fluorine, and methyl are 1.50, 1.99, and 2.77 Å., respectively.[17] The steric effect of β-fluorine should therefore be far less than half that of β-methyl. According to Ingold and coworkers the deactivating influence of α-methyl groups (compared to α-hydrogen) is partly steric and partly polar.[16] We believe that the data on the S_N2 reactivity of alkyl halides is explained more simply by the assumption that electron-donating groups increase and electron-withdrawing groups decrease S_N2 reactivity. This explains the present and earlier[3] data on the effect of β-halogen substituents and helps explain the effect

TABLE II

KINETIC DATA FOR REACTIONS WITH SODIUM THIOPHENOXIDE IN METHANOL

	10^5k (L. Mole^{-1} Sec.$^{-1}$)			$\Delta H\ddagger$,	$\Delta S\ddagger$,
	0°	20°	40°	Kcal./Mole	E.U.
CH_3CH_2I	408 ± 5	2600 ± 30		14.2 ± 0.2	−16.5 ± 0.8
FCH_2CH_2I	15.1 ± 0.1	166 ± 2		18.5 ± 0.2	−8.0 ± 0.6
F_2CHCH_2I	611 ± 6[a]	7.34[b]	77.0 ± 0.4	20.8 ± 0.2	−6.4 ± 0.5
F_3CCH_2I	14.0 ± 0.2[a]	0.149[b]	1.67 ± 0.03	21.4 ± 0.4	−12.1 ± 1.2

[a] At 60°. [b] Extrapolated from data at 40° and 60°.

RESULTS AND DISCUSSION

Table II shows that the continued introduction of β-fluorine atoms causes a continued decrease in S_N2 reactivity. In Fig. 1 a plot of log k/k_0 (where k is the rate constant for the compound in question and k_0 is that for the unsubstituted ethyl halide) *vs.* the number of β-fluorine substituents does not deviate greatly from linearity. The deactivating influence of the fluorine atoms may be practically entirely polar with the observed curvature of the plot being due to a saturation effect.[13] It seems more probable that the curvature is due more to a steric effect, however. Since steric effects tend to increase quite sharply with increasing crowding once they have become at all important, the curvature shown by the plot for the fluorine compounds seems too small to arise from a major steric effect. For purposes of comparison, a plot of the data on the reactivity of increasingly β-methylated ethyl bromides toward iodide ion at 25°[14] is also given in Fig. 1. The influence of the three β-methyl groups of neopentyl halides is rather generally agreed to be steric in character[15,16] and is seen in the Figure to be only slightly larger than that of three β-fluorine atoms. The curvature of the line for the β-methyl compounds is far more pronounced than that for the fluoro compounds. It thus seems likely that the effect of the fluoro atoms is largely polar. This conclusion is supported by the fact that fluorine atoms are nearer in size to hydrogen atoms than to methyl groups. The covalent radius plus the van der Waals radius for hydrogen, fluorine, and methyl are 1.50, 1.99, and 2.77 Å., respectively.[17] The steric effect of β-fluorine should therefore be far less than half that of β-methyl. According to Ingold and coworkers the deactivating influence of α-methyl groups (compared to α-hydrogen) is partly steric and partly polar.[16] We believe that the data on the S_N2 reactivity of alkyl halides is explained more simply by the assumption that electron-donating groups increase and electron-withdrawing groups decrease S_N2 reactivity. This explains the present and earlier[3] data on the effect of β-halogen substituents and helps explain the effect of α-halogen substituents.[18] It has been pointed out previously that no complete explanation has been given for the available data on S_N2 reactivities.[19] The generalizations that correctly predict one set of data seem to fail when applied to another. The data remaining unexplained usually include some of the following: Some S_N2 reactions of benzyl halides are speeded by both electron-withdrawing and electron-donating substituents.[19] The reactivity of β-

(12) S. Glasstone, K. J. Laidler, and H. Eyring, "The Theory of Rate Processes," McGraw-Hill Book Co., Inc., New York, N.Y., 1941, p. 14.

(13) *Cf.* J. Hine, N. W. Burske, M. Hine, and P. B. Langford, *J. Am. Chem. Soc.*, 79, 1406 (1957).

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(16) I. Dostrovsky, E. D. Hughes, and C. K. Ingold, *J. Chem. Soc.*, 173 (1946); P. B. D. de la Mare, L. Fowden, E. D. Hughes, C. K. Ingold, and J. D. H. Mackie, *J. Chem Soc.*, 3200 (1955).

(17) L. Pauling, *Nature of the Chemical Bond*, 2nd ed., Cornell University Press, Ithaca, New York, 1945, pp. 164, 189.

(18) J. Hine, C. H. Thomas, and S. J. Ehrenson, *J. Am. Chem. Soc.*, 77, 3886 (1955); J. Hine, S. J. Ehrenson, and W. H. Brader, Jr., 78, 2282 (1956).

(19) Ref. 2, sec. 6-3b.

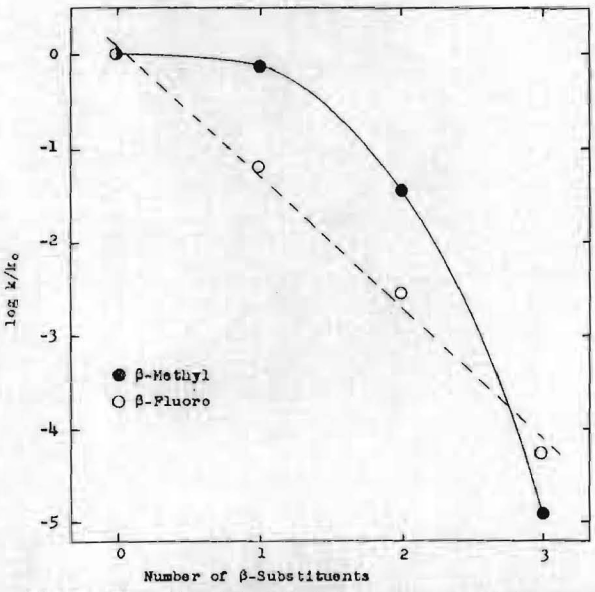

Fig. 1. Plot of log (k/k_0) for S_N2 reactions of ethyl iodides *vs.* the number of β-fluorine or β-methyl substituents

phenylethyl chlorides toward iodide in acetone is increased by both *p*-methoxy and *p*-nitro groups.[19] Both α- and β-halogen substituents decrease S_N2 reactivity to an extent that is proportional to neither their polar nor steric factors alone.[19] α-Haloketones (and also γ-chlorobutyrophenone[20]) are quite reactive.[19] In the β-position alkoxy groups deactivate and in the α-position they activate.[19,21] Benzyl and allyl halides are often more reactive than the corresponding methyl halides.[19]

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(20) J. B. Conant, W. R. Kirner, and R. E. Hussey, *J. Am. Chem. Soc.*, **47**, 488 (1925).

(21) P. Ballinger, P. B. D. de la Mare, G. Kohnstam, and B. M. Prestt, *J. Chem. Soc.*, 3641 (1955).

APPENDIX II

[Contribution from the School of Chemistry of
the Georgia Institute of Technology]

Methylene Derivatives as Intermediates in Polar Reactions. XX. The Reactions of Aqueous and Alcoholic Base with Chlorodifluoromethane and Difluoroiodomethane.[1]

By Jack Hine and Arthur D. Ketley

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(1) This work was supported in part by the U. S. Atomic Energy Commission. For the preceding article in this series see J. Hine, A. D. Ketley and K. Tanabe, J. Am. Chem. Soc., 82, 0000 (1960).

We have reinvestigated a report that with 15% potassium hydroxide in ethanol for 48 hours at 35°, $CHClF_2$, $CClF_2I$ and $CHIF_2$ gave no reaction, 24% $CHClF_2$ and 19% CH_2F_2, respectively. It was found that $CHClF_2$ reacts essentially completely with ethanolic potash within a few minutes and that $CHIF_2$ yields no more than 5%, if any, CH_2F_2. Rate constants were determined for the reaction of CHF_2I with hydroxide ion in aqueous solution. From the results obtained it appears that the reaction is initiated by a concerted α-dehydroiodination to yield difluoromethylene directly in one step.

Introduction

Haszeldine has reported that $CHClF_2$ is stable to the action of 15% potassium hydroxide in 95% ethanol for 48 hours at 35°,[2] and that under the same

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(2) R. N. Haszeldine, J. Chem. Soc., 4259 (1952).

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conditions $CClF_2I$ yields 24% $CHClF_2$ and that $CHIF_2$ yields 19% CH_2F_2. Our

observations that $CHClF_2$ is quite reactive toward aqueous alkali,[3] sodium methoxide[4] and potassium isopropoxide[5] caused us to doubt the first two reports.

(3) J. Hine and P. B. Langford, J. Am. Chem. Soc., 79, 5497 (1957).

(4) J. Hine and J. J. Porter, ibid., 79 4493 (1957).

(5) J. Hine and K. Tanabe, ibid., 80, 3002 (1958).

For the latter two reported reactions the mechanisms

$$CClF_2I \xrightarrow{OH^-} CClF_2^- \xrightarrow{\text{solvent}} CHClF_2$$

and

$$CHF_2I \xrightarrow{OH^-} CHF_2^- \xrightarrow{\text{solvent}} CH_2F_2$$

were suggested.[2] In view of our evidence that attempts to generate the $CClF_2^-$ anion instead bring about the concerted formation of the intermediate CF_2 and thence its reaction products,[3,6] the reaction reported for $CClF_2I$

(6) J. Hine and D. C. Duffey, ibid., 81, 1131 (1959).

seemed improbable, and in view of our observation that α-fluorine is the least effective of the α-halogen substituents at facilitating carbanion formation[7] we doubted the formation of a methylene halide reported from CHF_2I

(7) J. Hine, N. W. Burske, M. Hine and P. B. Langford, ibid., 79, 1406 (1957).

but not CHClIF nor CHI_2F). We have therefore reinvestigated some of these points and also carried out some related experiments of interest.

Results and Discussion

We have found that when solutions of $CHClF_2$ and potassium hydroxide in ethanol are mixed at 35° a copious precipitate of potassium chloride is formed within minutes. Titrations revealed that the theoretical amount of chloride ion (± 5%) was formed within five minutes. This observation makes the report of a 24% yield of $CHClF_2$ formed (from $CClF_2I$) after 48 hours in ethanolic KOH[2] difficult to understand.

The volatile products of the reaction of CHF_2I with ethanolic potassium hydroxide were studied in a number of runs. Fluoroform, ethyl difluoromethyl ether and varying amounts of starting materials were found but no clear evidence for methylene fluoride formation could be obtained. Experiments with authentic methylene fluoride showed that not more than about 5% could have been formed and remained undetected.

In order to learn more about the mechanism of the reaction of CHF_2I with base the kinetics of the reaction with aqueous sodium hydroxide was studied. This haloform proved to be the most reactive that has been studied[8] and for

(8) J. Hine and S. J. Ehrenson, J. Am. Chem. Soc., 80, 824 (1958).

this reason and its relatively volatile character the rate constants obtained, particularly at the higher temperatures, are less reliable than most of those reported previously. The second-order rate constants observed are $(0.96 \pm 0.08) \times 10^{-2}$, $(6.0 \pm 0.4) \times 10^{-2}$, and $(51.8 \pm 4) \times 10^{-2}$ (all in l. $mole^{-1}$ $sec.^{-1}$) at 0°, 21.2° and 40°, respectively. Thus difluoroiodomethane is around one thousand times as reactive toward hydroxide ion in aqueous solution as is methyl iodide[9] at the temperatures we have employed. In view of the fact that one

(9) E. A. Moelwyn-Hughes, Proc. Roy. Soc. (London), A196, 540 (1959).

α-fluoro substituent has been found to decrease the S_N2 reactivity of methyl halides[10] the reaction of difluoroiodomethane seems to be much too rapid to

(10) J. Hine, C. H. Thomas and S. J. Ehrenson, J. Am. Chem. Soc., 77, 3886 (1955); J. Hine, S. J. Ehrenson and W. H. Brader, Jr., ibid., 78, 2282 (1956).

be proceeding by the S_N2 mechanism, and therefore more probably involves a dihalomethylene intermediate. Although the rate of carbanion formation that would be expected for CHF_2I cannot be predicted very precisely, from the data obtained on related compounds[7,8,11] it does not seem probable that the rate

(11) J. Hine, R. Butterworth and P. B. Langford, ibid., 80, 819 (1958).

constant in water at 0° would be greater than about 10^{-3} l. $mole^{-1}$ $sec.^{-1}$ It therefore seems likely that since CHF_2I hydrolyzes faster than it would be expected to form carbanions, it hydrolyzes by a concerted mechanism in which there is no carbanion intermediate, but in which difluoromethylene is formed in a single step, as proposed earlier for $CHBrF_2$ and $CHClF_2$.[3]

Experimental

Difluoroiodomethane.--When mercuric fluoride was allowed to react with iodoform in the manner described previously in the preparation of fluorodiiodomethane[11] about a 30% yield of difluoroiodomethane, b. p. 21-22°, was obtained from liquid collected in a dry-ice trap at the end of the system and from the forerun of the fluorodiiodomethane distillation. Ruff reported a boiling point of 21.6° for the compound.[12] Some material was also made by the reaction of mercuric fluoride with fluorodiiodomethane.

(12) O. Ruff, Ber., 69, 299 (1936).

Reactions of Chlorodifluoromethane.--Chlorodifluoromethane[13] was bubbled

(13) The material used has been described previously.[4]

into 95% ethanol at room temperature to prepare a solution. When this solution at 35° was added to an equal volume of 15% ethanolic potassium hydroxide at the same temperature a copious precipitate of potassium chloride began to form within a minute or two. After 10 minutes the chloride formed from 10 ml. of the haloform solution was found to require 10.4 ml. of 0.0579 M silver nitrate solution for titration. Another 10-ml. sample from the same solution was found to require 10.9 ml. of the silver nitrate solution after 1020 minutes.

Reaction of Difluoroiodomethane.--In a typical reaction with alcoholic potassium hydroxide, 1.0 ml. of difluoroiodomethane was added to 100 ml. of 15% potassium hydroxide in 95% ethanol in an apparatus designed to capture any gaseous products. A vigorous reaction immediately ensued and the infrared spectrum of the gaseous products, including those given off after the reaction solution was heated to boiling, revealed the presence of only fluoroform, ethyl difluoromethyl ether and a little unreacted difluoroiodomethane. Because of similarities in absorption spectra a little methylene fluoride could have escaped detection but not enough to account for more than a 5% yield. Separate experiments on methylene fluoride showed that under the reaction conditions used it would not have been decomposed and it would have been evolved as a gas from the reaction solution.

Kinetic Runs.--The kinetics of reaction of difluoroiodomethane with hydroxide ion in aqueous solution was studied by a method like that described previously for bromodifluoromethane.[3] In a run at 0.0°, the first and sixth samples of

Table I

Reaction of Difluoroiodomethane with Aqueous Sodium Hydroxide at 0.0°

Time (sec.)	$\underline{N}^a$ CHF_2I	$[NaOH]_t^b$	100 k
507	0.04104	0.00785	1.130
801	0.04098	0.00712	1.032
1127	0.04092	0.00657	0.923
1500	0.04086	0.00578	0.924
2000	0.04074	0.00500	0.895
2880	0.04068	0.00405	0.830
		Ave.	0.956 ± 0.084

[a] The normality of haloform is 3 + f times the molarity.

[b] $[NaOH]_o$ = 0.00987.

haloform solution taken were found, by reaction with excess alkali, to be 0.04110 and 0.04080 N in haloform. It was assumed that the haloform concentration in the other samples varied linearly in the order that the samples were taken. The data obtained in this run are listed in Table I. In most of the other runs made the rate constants fell to a greater or smaller extent than those given in Table I. We do not know the reason for this fall but its existence suggests that the average rate constant may be less reliable than indicated by the average deviation. Because of the speed of the reaction and the volatility of the haloform the rate constants obtained at higher temperatures may be even less reliable.

Atlanta, Georgia

APPENDIX II

[Contribution from the School of Chemistry of the
Georgia Institute of Technology]

The Kinetics of the Base-Catalyzed Deuterium Exchange of 2,2-Dihalo-1,1,1-trifluorcethanes[1]

by Jack Hine, RobertWiesboeck and Robert G. Ghirardelli

(1) Part X in the series "The Effect of Halogen Atoms on the Reactivity of Other Halogen Atoms in the Same Modecule;" for part IX see J. Hine and R. J. Rosscup, THIS JOURNAL, 82, 0000 (1960).

The base-catalyzed deuterium exchange of CF_3CDCl_2, $CF_3CDBrCl$, CF_3CDBr_2 and CF_3CDI_2 was found to proceed with negligible interference from base-consuming side reactions. Kinetics of the exchange were studied in water and methanol and the following reactivity sequence noted: $CF_3CDBr_2 > CF_3CDI_2 \sim CF_3CDBrCl > CF_3CDCl_2$. By studies on CF_3CHCl_2 and $CF_3CHBrCl$ in heavy water the deuterium kinetic isotope effects were estimated to be 1.26 and 1.41, respectively. The trifluoromethyl substituent appears to be equal to or superior to the fluoro substituent at facilitating carbanion formation.

INTRODUCTION

Previous articles on the kinetics of the base-catalyzed deuterium exchange of haloforms have shown that α-halogen substituents facilitate carbanion formation in the order I ~Br > Cl > F.[2] This order, being almost exactly the revers

(2) J. Hine, N. W. Burske, M. Hine and P. B. Langford, THIS JOURNAL, 79, 1406 (1957).

of the relative electronegativities of the halogens, did not agree with some of the existing explanations of the activity of the hydrogen atoms of haloforms. It would be desirable to learn the effect of more distantly situated halogen substituents on the ease of carbanion formation. For example, one of the strongest points of evidence that the dehydrohalogenations of most saturated organic halides (and many other elimination reactions) are concerted E2 reactions that do not involve intermediate carbanions is the fact that many such reactions are much faster than seems plausible for carbanion formation.[3]

(3) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, p. 169.

The most obvious loophole in this argument is our ignorance of the effect of β-halogen substituents on ease of carbanion formation.

Fluorobenzene has been found to form carbanions at its ortho position quite rapidly in the presence of potassium amide in liquid ammonia but the rate at which the other monohalobenzenes do so is unknown and may also be quite fast.[4] The interpretation of the semi-quantitative experiments of

(4) G. A. Hall, R. Piccolini and J. D. Roberts, THIS JOURNAL, 77, 4540 (1955); J. D. Roberts, D. A. Semenow, H. E. Simmons, Jr. and L. A. Carlsmith, ibid., 78, 601 (1956).

Miller and Lee on the deuterium exchange of the dihaloethylenes[5] is complicated

(5) S. I. Miller and W. G. Lee, ibid., 81, 6313 (1959).

by the simultaneous changing of both an α- and a β-substituent. However, if it is assumed that the α-halogen substituents on these unsaturated compounds have the same relative effect that has been observed with the haloforms, then it follows that the β-halogen substituents facilitate carbanion formation in the order Cl > Br > I.

The rates of formation of β-halo carbanions cannot be studied in the cases of most saturated organic halides because of the incursion of a much faster concerted elimination reaction or because the competing olefin formation makes it impossible to capture and hence prove the intermediacy of the carbanion. However, it seemed to us that a carbanion that was stabilized by α-halogen substituents and that could form an olefin only by loss of a fluoride ion might have a long enough life to be reprotonated. We have therefore studied some 2,2-dihalo-1,1,1-trifluoroethanes.

RESULTS AND DISCUSSION

All of the 2,2-dihalo-1,1,1-trifluoroethanes studied were found to undergo base-catalyzed deuterium exchange at a rate rapid compared to the rate at which they consumed alkali. Upon treatment with alkaline heavy water their infrared spectra were found to change in a manner that was plausible for a deuteriation process. When the deuteriated materials were treated with alkaline protium oxide, the infrared spectral changes were found to be completely reversed, ruling out all other reasonable explanations for the original changes in spectra.

The kinetics of the exchange of the deuteriated halides were studied, with some runs being made in aqueous and others in methanolic solution. In no case was there any appreciable exchange with the solvent alone under the conditions used. With all of the compounds except 2,2-diiodo-1,1,1-trifluoroethane the deuterium exchange was so rapid compared to processes in which base was consumed that the reaction was cleanly first order in any given run. The second order character of the reaction was, however, established in several cases by the observation that the first order rate constants obtained in various runs on a given compound were proportional to the concentration of base used in these runs. Thus there seems little doubt that the reaction mechanism is

$$CF_3CDX_2 + B^- \rightarrow CF_3CX_2^- + BD$$

$$CF_3CX_2^- + BH \rightarrow CF_3CHX_2 + B^-$$

with the first step rate-controlling and essentially irreversible because of the large excess of the protiated solvent. The first order rate constants for the diiodide were found to fall slightly during the individual runs. Acidimetric titrations showed that this was due to a decrease in the base concentration resulting from some minor side reaction. When second order rate constants were calculated by dividing the first order rate constant obtained at a given point by the average base concentration present during the point the values obtained showed no significant drift. The second order rate constants obtained are listed in Table I with those obtained for the other compounds and the value determined roughly for 2,2-dichloro-1,1-difluoro-1-methoxyethane.

TABLE I HERE

The effect of the various α-halogen substituents on the rate of carbanion formation is qualitatively much like that observed in the case of the haloforms,[2] I $\sim$ Br > Cl, although the difference in reactivities is smaller and in the present case the diiodide is clearly less reactive than the dibromide, in methanol at least. The trifluoromethyl substituent probably stabilizes the carbanion by the contribution of no-bond resonance structures of the type suggested by Roberts, Clement and Drysdale.[6]

$$F\text{-}CF_2\text{-}\overset{\ominus}{C}X_2 \leftrightarrow \overset{\ominus}{F}\ CF_2{=}CX_2$$

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(6) J. D. Roberts, R. A. Clement and J. J. Drysdale, THIS JOURNAL, 73, 2181 (1951).

Table I

Rate Constants for Dueterium Exchange of

1,1-Dihalo-2,2,2-trifluoroethanes[a]

Reactant	10^3k (l. mole^{-1} sec.$^{-1}$) in D_2O[b] 0°	in H_2O 0°	in methanol 0°	in methanol 20°	Activation parameters in methanol $\Delta H^{\ddagger}$ kcal/mole	$\Delta S^{\ddagger}$ e.u.
CF_3CDCl_2	6.18 ± 0.24	3.53 ± 0.12	0.649 ± 0.007	10.2 ± 0.2	21.4	5.2
$CF_3CDBrCl$	21.8 ± 1	11.1 ± .3	1.66 ± .06	22.0 ± .6	20.0	2.1
CF_3CDBr_2		21.6 ± .4[c]	4.19 ± .15	74 ± 3	22.3	12.3
CF_3CDI_2		18.3 ± 1	1.40 ± .06	29.0 ± .7	23.6	14.8
$CH_3OCF_2CDCl_2$				~ .07		

[a]The ± figures listed are the average deviations; the experimental uncertainty is probably somewhat greater. The activation energies are believed reliable within 1 kcal and the activation entropies within 3 e.u. [b]The reactant in these runs is not the deuterium derivative listed but the corresponding hydrogen compound. [c]k = 3.5 ± 0.4 l. mole^{-1} sec.$^{-1}$ at 40°.

Its ability to facilitate carbanion formation relative to that of the halogen substituents is somewhat variable. For example CF_3CDCl_2 is 40 times as reactive as $FCDCl_2$ while CF_3CDI_2 is only 0.36 times as reactive as $FCDI_2$.[7] Some of these

(7) J. Hine, R. Butterworth and P. B. Langford, ibid., 80, 819 (1958).

irregularities can be explained by the hypothesis that with the trifluoromethyl substituent steric hindrance to the attack of the base has become of considerable importance. Thus we may assume that, disregarding steric effects, the α-halogen substituents facilitate carbanion formation in the order I > Br > Cl > F. In the case $CDI_2F > CDBr_2F$,[7] the polar factors predominate over steric hindrance; with somewhat bulkier molecules it is found that CDI_3 and CBr_3 are of comparable reactivity[2] and when the considerably larger trifluoromethyl group is present steric hindrance reduces the activity of CF_3CDI_2 below that of CF_3CDBr_2.

Unlike the results obtained with the haloforms, where the relative rates of carbanion formation seem to have been controlled by enthalpy factors, the present results seem to spring from a mixture of entropy and enthalpy effect. We have no convincing explanation for this result and it may simply come from experimental uncertainties.

The kinetic isotope effect may be estimated from the data obtained in heavy water solution by assuming as before[8] that deuteroxide ion in heavy water

(8) J. Hine and N. W. Burske, ibid., 78, 3337 (1956).

forms carbanions 39% faster than hydroxide ions in light water. The resultant values of k_H/k_D of 1.26 and 1.41 for CF_3CHCl_2 and $CF_3CHBrCl$ are somewhat smaller than those obtained for the haloforms (1.48 to 1.76 for carbanion formation[2,8] and 2.02 for concerted dehydrohalogenation[9]), but much smaller than that

(9) J. Hine and P. B. Langford, ibid., 79, 5497 (1957).

obtained in the reaction of CH_3OCHCl_2 with potassium isopropoxide (5.4 ± 2.2).[10]

(10) J. Hine, R. J. Rosscup and D. C. Duffey, ibid., 82, 0000 (1960).

With the k_H/k_D values in these simple carbanion formation reactions being so much smaller than the values (ca. 6) obtained in other carbanion formations[11]

(11) K. B. Wiberg, Chem. Rev., 55, 713 (1955).

and those obtained in other proton removals that appear to be concerted eliminations[9,10] it seems difficult to rule out the possibility that other hydrogen-transfer reactions proceeding at moderate rates will be found that have still smaller deuterium kinetic isotope effects. For this reason it would be well to view with skepticism the generalization that the absence of a marked deuterium kinetic isotope effect proves that a hydrogen is not being transferred in the rate-controlling step of a reaction.[12]

(12) Cf. L. Melander, Acta Chem. Scand., 3, 95 (1949).

The reactivities toward sodium methoxide in methanol are only about one-fifth as large as toward sodium hydroxide in water. A measurement on deuteriochloroform in methanol gave a second-order rate constant of 8.9×10^{-3} l. mole^{-1} sec.$^{-1}$ at 20.2°, about one-eleventh of the value found in water.[13] Part of

(13) J. Hine, R. C. Peek, Jr. and B. D. Oakes, THIS JOURNAL, 76, 827 (1954).

this decrease in rate is no doubt due to the fact that methoxide ions are weaker bases than hydroxide ions.[14]

(14) J. Hine and M. Hine, ibid., 74, 5266 (1952).

The observed deuterium exchange provides evidence that the dehydrohalogenation of these compounds proceeds by the carbanion mechanism,[3] a point that will be discussed in connection with a study of the alkali-consuming reactions of these halides.[15]

(15) J. Hine, R. Wiesboeck and O. B. Ramsay, ibid., 83, 0000 (1960).

EXPERIMENTAL

Reagents.--A modification of the method of Gilman and Jones[16] was used in the preparation of 2,2-diiodo-1,1,1-trifluoroethane, n_D^{22} 1.5375, d_4^{22} 2.600; reported[16] d_4^{22} 2.595. Methanol was purified as described by Fieser;[17]

(16) H. Gilman and R. Jones, THIS JOURNAL, 65, 1458 (1943).

(17) L. F. Fieser, "Experiments in Organic Chemistry," 2nd Ed., D. C. Heath and Co., Inc., Boston, Mass., 1941, p. 359.

2-bromo-2-chloro-1,1,1-trifluoroethane (Ayerst Laboratories) was fractionally distilled to give material of b.p. 49.8° (739 mm); 2,2-dichloro-1,1,1-trifluoroethane (du Pont) was purified by several bulb-to-bulb low pressure distillations; and 2,2-dichloro-1,1-difluoro-1-methoxyethane (n_D^{20} 1.4238, d_4^{20} 1.3862; reported n_D^{20} 1.4262, d_4^{20} 1.3861) was prepared from 2,2-dichloro-1,1-difluoroethylene by the method of Miller, Fager and Griswold.[18]

(18) W. T. Miller, Jr., E. W. Fager and P. H. Griswold, THIS JOURNAL, 70, 431 (1948).

2,2-Dibromo-1,1,1-trifluoroethane.--The method of preparation of 2,2-dibromo-1,1,1-trifluoroethane was analogous to that used for the corresponding diiodide. Trifluoroacetamide was reduced to trifluoroethylamine with lithium

aluminum hydride.[19] On two occasions, EXPLOSIONS OCCURRED DURING THE ADDITION

(19) E. J. Bourne, S. H. Henry, C. E. M. Tatlow and J. C. Tatlow, J. Chem. Soc., 4014 (1952).

OF WATER UNDER NITROGEN IN WORKING UP THIS REACTION MIXTURE. A solution of alcohol in ether should be used to decompose the initially-formed complex which should not be allowed to form any dry deposits on the inside of the flask.[20] To 45 g. (0.32 mole) of trifluoroethylamine hydrochloride in 150 ml.

(20) Cf. T. S. Reid and G. H. Smith, Chem. Eng. News, 29, 3042 (1951).

of water was added 300 ml. of methylene chloride and then at 0°, 21 g. (0.3 mole) of sodium nitrite over the period of an hour. After an additional half-hour, the organic layer was separated and the aqueous layer stirred for thirty minutes with 150 ml. of methylene chloride. The combined methylene chloride solutions were "titrated" with 0.5 M bromine in methylene chloride until about 350 ml. (0.175 mole bromine) had been added, at which time the red color of the bromine was no longer discharged. The solution was filtered and fractionally distilled to give 21 g. (27% based on amine hydrochloride) of 2,2-dibromo-1,1,1-trifluoroethane, b.p. 71-72° (745 mm), n_D^{25} 1.4041; D_4^{25} 2.219. Reported values are b.p. 73°, n_D^{26} 1.4029; d_4^{24} 2.224.[21]

(21) E. T. McBee, H. B. Hass, W. G. Toland, Jr. and A. Truchan, Ind. Eng. Chem., 39, 420 (1947).

Preparation and Analysis of 2-Deuterio-2,2-dihalo-1,1,1-trifluoroethanes.--In a typical experiment 4 g. of 2,2-dichloro-1,1,1-trifluoroethane was shaken with 5.5 ml. of 0.4 M NaOD in D_2O for twenty-four hours, separated, and the

process repeated. In the reaction product the 11.995μ absorption band of the protium compound had decreased in intensity to less than 1% of its original value, showing that more than 99% deuteriation had occurred. Extinction coefficients were determined for both the deuteriated and protiated materials at the 8.190 and 10.675μ bands characteristic of the deuteriated material and the 8.460 and 11.995μ bands of the protium compound.

In the case of 2,2-dibromo-1,1,1-trifluoroethane the 8.948 and 13.170μ bands of the deuterium compound and the 10.450 and 11.350μ bands of the protium compound were used. The deuteriated material was at least 97% isotopically pure.

For 2,2-diiodo-1,1,1-trifluoroethane, 2-bromo-2-chloro-1,1,1-trifluoroethane, and 2,2-dichloro-1,1-difluoro-1-methoxyethane, respectively, the 8.340, 11.025 and 10.620μ absorption bands of the deuterium compounds and the 9.145, 8.875 and 9.345μ bands of their protium analogs were used in the isotopic analysis. The compounds used were at least 98, 97 and 97% isotopically pure, respectively.

For those compounds whose isotopic analysis was carried out by measurements at four wave lengths two independent sets of results could be calculated, permitting an internal check on the analytical method. Since the rate of consumption of base was very small compared to the rate of deuterium exchange it is not necessary to know the isotopic content of the deuterium starting material, only the ratio of this content to the content at the times when points are taken during the runs.[2]

Kinetic Runs.--In a typical run, 343 mg. of deuteriated 2,2-dibromo-1,1,1-trifluoroethane was dissolved in 50 ml. of 0.00040 M methanolic perchloric acid. When this solution had cooled to 0°, 5-ml. samples were added to 5-ml. samples of 0.02559 M sodium methoxide in methanol in 25-ml. volumetric flasks also at 0°. The points were stopped at various times by the addition

of 8 ml. of 0.0343 M aqueous perchloric acid. They were extracted with 2-ml. portions of isooctane which were then dried with a small amount of silica gel and analyzed by infrared measurements. The results obtained are shown in Table II.

TABLE II HERE

In runs on dibromotrifluoroethane in aqueous solution at 40° in the presence of 0.03417 M ammonia-0.05019 M ammonium perchlorate a rate constant of (8.08 ± 0.45) x 10^{-5} sec.$^{-1}$ was obtained and with the same buffer ratio but only half the concentration a value of (7.30 ± 0.40) x 10^{-5} sec.$^{-1}$ was found. From the data of Everett and Wynne-Jones on the ionization of ammonia[22] values of 3.5 ± 0.4 l. mole^{-1} sec.$^{-1}$ and (4.6 ± 2) x 10^{-3} l. mole^{-1} sec.$^{-1}$ may be obtained as rate constants for carbanion formation due to the bases hydroxide ion and ammonia, respectively.

(22) D. H. Everett and W. F. K. Wynne-Jones, Proc. Roy. Soc., (London), A169, 190 (1938).

Acknowledgments.--We should like to acknowledge our indebtedness to the U. S. Atomic Energy Commission for partial support of this investigation and to E. I. du Pont de Nemours and Co. and Ayerst Laboratories, Inc. for gifts of chemicals.

Atlanta, Ga.

Table II

Kinetics of Base-catalyzed Exchange of CF_3CDBr_2 in Methanol at 0°[a]

Time, sec.	% CF_3CDBr_2[b]	$10^5 k_1$[b] $sec.^{-1}$	% CF_3CDBr_2[c]	$10^5 k_1$[c] $sec.^{-1}$
0	97.89		98.88	
1835	88.80	5.32	89.10	5.57
4151	79.20	5.16	78.67	5.51
5820	72.39	5.19	71.42	5.59
7100	67.40	5.26	66.75	5.52
9600	59.08	5.11	58.04	5.54
12600	50.22	5.29	49.14	5.55
14580	45.82	5.21	44.58	5.47
16200	41.56	5.29	41.16	5.42

Average $k_1 = 5.37 \pm 0.15 \times 10^{-5}$ $sec.^{-1}$

[a] In the presence of 0.01259 M sodium methoxide. [b] From measurements at 8.948 and 10.450μ. [c] From measurements at 11.348 and 13.170μ.

APPENDIX IV

[Contribution from the School of Chemistry of
the Georgia Institute of Technology]

The Carbanion Mechanism for the Dehydrohalogenation of 2,2-Dihalo-1,1,1-trifluoroethanes[1]

By Jack Hine, Robert Wiesboeck and O. Bertrand Ramsay

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(1) Part XI in the series "The Effect of Halogen Atoms on the Reactivity of Other Halogen Atoms in the Same Molecule." For part X see ref. 13.

Kinetic studies are reported for the reactions of 2,2-dichloro-1,1,1-trifluoroethane, 2-bromo-2-chloro-1,1,1-trifluoroethane, 2,2-dibromo-1,1,1-trifluoroethane, 2,2-diiodo-1,1,1-trifluoroethane, and 2,2-dichloro-1,1-difluoro-1-methoxyethane with sodium methoxide in methanol and for the sodium methoxide-catalyzed addition of methanol to 1,1-dichloro-2,2-difluoroethylene. Arguments are presented to show that the pentahaloethanes studied undergo dehydrofluorination via an intermediate carbanion to give a tetrahaloethylene that rapidly adds methanol to give a methyl pentahaloethyl ether, which then reacts with sodium methoxide at a rate comparable to that of the reactant pentahaloethane. The factors that favor the carbanion mechanism (relative to the concerted E2 mechanism) for elimination are discussed. The relative reactivities, $CF_3CHI_2 > CF_3CHBr_2 > CF_3CHBrCl > CF_3CHCl_2$, are rationalized in terms of the carbanion elimination reaction.

INTRODUCTION

It seems rather generally accepted that the base-catalyzed dehydrohalogenation of most saturated aliphatic halides brought about by such bases as potassium hydroxide and sodium ethoxide is a concerted one-step process called

the E2 mechanism.[2,3] Another reaction mechanism that would fit the same

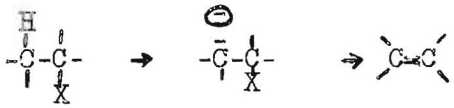
(2) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, sec. 7-1a.

(3) The term "E2" seems to be used by some to include both the concerted and stepwise mechanisms and by others to refer only to the concerted process. We shall use the latter terminology here, with the frequent addition of "concerted" for clarity.

bimolecular reaction kinetics has been called the carbanion mechanism[2] or the ElcB mechanism.[4] In this mechanism the basic reagent removes from the β-carbon

(4) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, Ithaca, N. Y., 1953, sec. 30a.

atom a hydrogen atom without its bonding electron pair, leaving a carbanion that rapidly loses a halide ion to give the olefin.



(1)

Hughes, Ingold and Patel pointed out that the decomposition of the 2-(p-nitrophenyl)ethyltrimethylammonium ion to p-nitrostyrene, which proceeds much faster in neutral solution than in 0.5 M hydrochloric acid, probably follows the carbanion mechanism.[5] While it is probable that acid slows the reaction

(5) E. D. Hughes and C. K. Ingold, J. Chem. Soc., 523 (1933); E. D. Hughes, C. K. Ingold and C. S. Patel, ibid., 526 (1933).

by protonating intermediate carbanions that would otherwise have lost trimethylamine to give olefin, it is possible that the decomposition in neutral solution is a concerted elimination involving hydroxide ion, whose concentration is much smaller in acid solution, of course. The carbanion mechanism

seems first to have been established by the observation that trichloroethylene undergoes base-catalyzed deuterium exchange considerably faster than it undergoes dehydrohalogenation.[6] Observations of varying amounts of deuterium

(6) L. C. Leitch and H. J. Bernstein, Can. J. Research, 28B, 35 (1950); T. J. Houser, R. B. Bernstein, R. G. Miekka and J. C. Angus, THIS JOURNAL, 77, 6201 (1955).

exchange of unreacted starting material have also been used to support the carbanion mechanism for various dihaloethylenes,[7] β-benzene hexachloride,[8] malic acid,[9] and fluorobenzene.[10] The carbanion mechanism has also been

(7) S. I. Miller and W. G. Lee, ibid., 81, 6313 (1959).

(8) S. J. Cristol and D. D. Fix, ibid., 75, 2647 (1953).

(9) L. E. Erickson and R. A. Alberty, J. Phys. Chem., 63, 705 (1959).

(10) G. A. Hall, R. Piccolini and J. D. Roberts, THIS JOURNAL, 77, 4540 (1955); J. D. Roberts, D. A. Semenow, H. E. Simmons, Jr. and L. A. Carlsmith, ibid., 78, 601 (1956).

inferred from the magnitude of the deuterium kinetic isotope effect in the reaction of chlorobenzene with potassium amide[10] and a kinetic argument has been presented that the decomposition of 1,1,1,3-tetranitro-2-phenylpropane to nitroform and β-nitrostyrene in methanol solution also proceeds by the carbanion mechanism.[11]

(11) J. Hine and L. A. Kaplan, ibid., 82, 0000 (1960).

While it thus seems clear that some basic elimination reactions involve intermediate carbanion formation it also seems clear that others do not. Lack of deuterium exchange of the reactant[12] seems to be necessary but not sufficient

(12) Cf. P. S. Skell and C. R. Hauser, ibid., 67, 1661 (1945).

evidence for the concerted E2 mechanism, since it leaves the possibility that a carbanion is formed but practically never protonated to regenerate the starting material. Probably stronger evidence is the fact that many dehydrohalogenations proceed much more rapidly than carbanions would be expected to be formed under the conditions. For example, the carbanion mechanism does not explain the preferential trans character of the reaction since cis hydrogens would be expected to be removed to form carbanions about as fast as the corresponding trans hydrogens in at least some of the cases that have been studied. Other examples could be given but in general we feel that the effective use of the reactivity criterion to delineate the areas of applicability of the E2 and carbanion mechanisms demands more data on the effect of substituents (particularly β-halo substituents) on reactivity in carbanion formation. For this reason and also because the carbanion mechanism has not yet been shown to operate for any saturated aliphatic halide, we have studied the deuterium exchange of some 2,2-dihalo-1,1,1-trifluoroethanes,[13] and are now studying the reactions in which these halides consume base.

(13) J. Hine, R. Wiesboeck and R. G. Ghirardelli, ibid., 82, 0000 (1960).

RESULTS AND DISCUSSION

Evidence for Elimination.--When the four 2,2-dihalo-1,1,1-trifluoroethanes studied were treated with sodium methoxide under conditions considerably more

severe than those required for deuterium exchange[13] methoxide ions were consumed. In all cases fluoride ions were formed. At 70.5° about 11% of the methoxide consumed liberated iodide ions from the diiodo compound but not more than 4% of bromide and/or chloride was formed from the dibromo, bromochloro or dichloro compounds. Within the experimental error the total concentration of halide ions formed was equal to the concentration of methoxide ions that reacted.

Although no product studies have been made, the only plausible course for the liberation of the fluoride ions is the dehydrofluorination of the reactant. The olefinic product of one of the reactions, 1,1-dichloro-2,2-difluoroethylene, is known to add alcohol readily in the presence of a basic catalyst.[14]

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(14) W. T. Miller, Jr., E. W. Fager and P. H. Griswold, ibid., 70, 431 (1948).

$$CF_3CHCl_2 + MeO^- \rightleftarrows CF_3CCl_2^- + MeOH$$

$$CF_3CCl_2^- \rightarrow Cl^- + CF_2 = CCl_2$$

$$CF_2=CCl_2 + MeO^- \rightarrow MeOCF_2CCl_2^-$$

$$MeOCF_2CCl_2^- + MeOH \rightleftarrows MeOCF_2CHCl_2 + MeO^-$$

In fact, we made measurements showing that while this dichlorodifluoroethylene is stable in neutral methanol for hours, in the presence of 0.00945 M sodium methoxide it undergoes a first-order reaction (rate followed by infrared measurements) with a rate constant of $(2.9 \pm 0.4) \times 10^{-4}$ sec.$^{-1}$ at 0° to give 2,2-dichloro-1,1-difluoro-1-methoxyethane. Assuming that the reaction is second order the second-order rate constant is 3×10^{-2}. This value being more than 10^8 times as large as the second-order rate constant for the reaction of 2,2-dichloro-1,1,1-trifluoroethane with sodium methoxide (extrapolated from data at higher temperatures--see Table I) we would not expect it to be possible

to isolate significant amounts of the dichloro-difluoroethylene as a reaction product under the conditions we employed.

In view of the fact that product-isolation experiments could therefore not be useful in establishing the nature of the initial fluoride-producing reaction, the arguments against all reaction paths other than dehydrofluorination should be given in some detail. While such reactions as methylene formation[15]

$$CF_3CHCl_2 \xrightarrow{MeO^-} CF_3CCl_2^- \rightarrow CF_3\text{-}C\text{-}Cl + Cl^-$$

and nucleophilic displacement of halogens other than fluoride might seem probable, our experimental observations show that at 70.5° such reactions occur

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(15) Cf. J. Hine and S. J. Ehrenson, ibid., 80, 824 (1958) and references cited therein.

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to the extent of no more than 11% (and probably to an extent of less than 5.5% when it is considered that the replacement of one iodine, bromine or chlorine by methoxy would probably so activate the remaining one as to bring about its almost immediate replacement[16,17]). The dependence of the reaction

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(16) Cf. P. Ballinger, P. B. D. de la Mare, G. Kohnstam and B. M. Prestt, J. Chem. Soc., 3641 (1955).

(17) J. Hine, C. H. Thomas and S. J. Ehrenson, THIS JOURNAL, 77, 3886 (1955).

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rate on the methoxide ion concentration rules out any first-order reactions of the halide. Therefore the only plausible possibilities that remain are dehydrofluorination and the S_N2 displacement of fluorine by methoxide ions. However, our compounds liberate fluoride at a rate that appears to be unreasonably fast for the S_N2 mechanism. They are from 100 to 1000 times as reactive toward

sodium methoxide in methanol as typical primary fluorides are toward sodium ethoxide in ethanol.[18] Since α- and β-halogen substituents have been found to decrease S_N2 reactivity in the cases that have been studied[17,19,20] these

(18) N. B. Chapman and J. L. Levy, J. Chem. Soc., 1673 (1952).

(19) J. Hine, S. J. Ehrenson and W. H. Brader, Jr., THIS JOURNAL, 78, 2282 (1956).

(20) J. Hine and W. H. Brader, Jr., ibid., 75, 3964 (1953).

dihalotrifluorides should be less reactive than unsubstituted primary fluorides. The change in reagent and solvent seems unlikely to increase the reactivity greatly in view of the fact that ethyl bromide is about twice as reactive toward ethoxide in ethanol[21] as toward methoxide in methanol.[17] We have therefore concluded that the reaction consists very largely of an initial dehydrofluorination.

(21) E. D. Hughes, C. K. Ingold, S. Masterman and B. J. McNulty, J. Chem. Soc., 899 (1940).

The rapid subsequent addition of methanol to the difluorodihaloethylene will have no effect on our kinetic studies, in which the reaction was followed by measurements of methoxide and fluoride ion concentrations, but the difluorodihaloethyl methyl ether produced does undergo dehydrohalogenation, giving decreased reliability to our rate constants for the reactions of the 2,2-dihalo-1,1,1-trifluoroethanes listed in Table I. We have attempted to take this and other relevant factors into account in arriving at the listed uncertainties, which are considerably larger than the average deviations obtained.

Table I

Kinetics of Dehydrofluorination of 2,2-Dihalo-1,1,1-trifluoroethanes by Methanolic Sodium Methoxide

	$10^6 k$		$\Delta H^{\ddagger}$	$\Delta S^{\ddagger}$
	55.0°	70.5°	kcal/mole[a]	e.u.[a]
CF_3CHCl_2	1.5 ± 0.2	19 ± 2[b]	37.2	28
$CF_3CHBrCl$	2.9 ± 0.3	33 ± 4	34.5	21
CF_3CHBr_2	5.5 ± 1	56 ± 5	32.9	17
CF_3CHI_2	51 ± 10	490 ± 50	32.0	19
$CH_3OCF_2CHCl_2$	3.0 ± 0.2	27 ± 2	31.1	11

[a]The uncertainties in $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ are estimated at 3 kcal/mole and 9 e.u., respectively. [b]At 70.0°.

The Carbanion Elimination Mechanism.--The occurrence of deuterium exchange, rapid compared to the rate of elimination, as in the present case,[13] has generally been accepted as proof of the carbanion mechanism for elimination. One might object that the deuterium exchange does not prove that carbanions were being formed since the exchange could have occurred by a concerted mechanism. However, since no base-catalyzed exchange reaction of carbon-bound hydrogen has yet been shown to be a one-step process, while there is strong evidence that many such reactions proceed via carbanions, we shall assume that there was carbanion formation in the present case. A second possible objection is that the carbanion formation is simply an irrelevant side reaction, having nothing to do with the elimination reaction. However even in a concerted E2 reaction,

the function of the removal by base of β-hydrogen without its bonding electron pair must be to liberate this electron pair so that it can be used as the second electron pair of the double bond that is being produced. In the concerted reaction the partial removal of the β-hydrogen and the concommitant partial freeing of the bonding electron pair is sufficient to cause the beginning of the formation of the double bond and the ejection of the halide ion (or other group) with its bonding electron pair. If this partial freeing of a β-electron pair is enough to bring about the ejection of the halide ion it is difficult to understand why the complete freeing of the electron pair, as in carbanion formation, should not bring about the ejection of a halide ion even more effectively, unless the carbanion is being formed from a rotational conformer that is inactive toward the concerted E2 reaction or unless the freeing of the β-electron pair must be synchronized with certain vibrations of the group being ejected with its bonding electron pair and/or the four groups attached to the double bond of the olefin that is being formed. The dehydrohalogenation of the 2,2-dihalo-1,1,1-trifluoroethanes cannot be complicated by conformational isomerism since all three conformers are identical.[22] Furthermore,

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(22) The deuterium exchange observed with β-benzene hexachloride,[8] however, may involve the formation, from the predominant all-equatorial conformer, of carbanions, some of which are reprotonated before they are transformed to a conformer from which a chloride ion is more rapidly ejected.

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if the carbanions are true intermediates (corresponding to energy minima in a potential energy versus molecular geometry plot) then they must be more abundant (having a lower energy content) than the species in which the hydrogen has been <u>almost</u> removed and the carbanion almost formed. This being the case, it is in

the carbanions that the presence of an excess of electrons on the β-carbon atom is by far the most likely to become synchronized with the proper vibrations of the other parts of the molecule so as to result in transformation to the olefin. It therefore seems unlikely that any major part of the elimination reaction proceeds by a concerted E2 mechanism.

All of the existing reports[5-11] seem to be in agreement with the generalization that the carbanion mechanism for base-catalyzed elimination reactions can be made more important relative to the E2 mechanism by (1) changing X (in eq. 1) so as to decrease its ease of departure with its bonding electron pair, (2) introducing structural features so as to stabilize the possible intermediate carbanion,[23] and (3) decreasing the stability of the unsaturated compound

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(23) Cf. ref. (4), footnote 12.

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being formed by the elimination (the stability of acetylenes relative to the corresponding olefins is usually less than that of olefins relative to the corresponding saturated compounds) and (4) inhibiting the E2 reaction by preventing H and X from being oriented trans to each other. The first three of these factors seem to be important in the present case. It is well known to be difficult to displace fluorine from organic molecules, especially when there are several other fluorine atoms attached to the same carbon atom.[17,24] The

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(24) Cf. ref. 2, p. 167 and A. L. Henne in "Organic Chemistry," 2nd ed., ed. by H. Gilman, John Wiley and Sons, Inc., New York, N. Y., 1943, pp. 959-961.

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intermediate carbanion is fairly well stabilized by two α-halogens and three β-fluorines.[13] It has been suggested earlier that fluorine substituents destabilize olefins relative to related saturated compounds because of a

decrease in that part of the C-F bond energy due to the difference in electronegativity of the two atoms.[25] More direct evidence for this suggestion may be found in the studies of Lacher, Park and coworkers on the heats of reaction of certain fluoroolefins.[26]

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(25) J. Hine and P. B. Langford, THIS JOURNAL, 78, 5002 (1956).

(26) J. R. Lacher, A. Kianpour and J. D. Park, J. Phys. Chem., 61, 584 (1957); J. R. Lacher, L. Casali and J. D. Park, ibid., 60, 608 (1956); J. R. Lacher, A. Kianpour, P. Montgomery, H. Knedler and J. D. Park, ibid., 61, 1125 (1957).

Relative Reactivities.--The relative rates of dehydrofluorination of the dichloro, bromochloro and dibromo compounds are about the same as their relative rates of carbanion formation.[13] This suggests that the transition state for olefin formation still has a large amount of carbanion character and that the difference in the behavior of the three compounds can be attributed largely to the differing abilities of the two α-halogen atoms to stabilize carbanions. The diiodo compound is dehydrofluorinated significantly more rapidly, however, although its carbanion formation rate is no faster than that of some of the other compounds studied. This tendency of the 1,1-diiodo-2,2,2-trifluoroethyl anion to decompose to olefin a considerably higher percentage of the times that it is formed must, from the principle of microscopic reversibility, be partly due to steric interference in protonation of the carbanion if our suggestion of the importance of steric effects in carbanion formation from these pentahaloethanes[13] is correct. Decreased stability of the saturated reactant relative to the olefinic product in the case of the diiodo compound, perhaps resulting from greater crowding of the bulky iodine atoms in the sp^3 hybridized pentahaloethane than in the sp^2 hybridized olefin, may also be important.

The 1,1-dichloro-2,2-difluoro-2-methoxyethyl anion would also be expected to decompose to olefin a relatively higher percentage of the time that it is formed in view of the fact that the olefin produced would have only one destabilizing fluorine substituent. Comparison of rates of deuterium exchange[13] and sodium methoxide consumption suggests that this does occur but, as the α-methoxy substituent is known to increase S_N2 reactivity,[16,17] there is some possibility that the reaction with sodium methoxide is largely a substitution rather than elimination process.

EXPERIMENTAL

The reagents used have been described previously.[13]

Kinetics of the Addition of Methanol to 2,2-Dichloro-1,1-difluoroethylene.--To 100 ml. of 0.00945 M sodium methoxide in methanol at 0° was added 0.080 ml. of the dichlorodifluoroethylene. As soon as possible after shaking, a 10-ml. sample was taken, added to 10 ml. of 0.07 M aqueous perchloric acid and extracted with 2 ml. of carbon tetrachloride. The extract was dried with a little silica gel and analyzed for 2,2-dichloro-1,1-difluoro-1-methoxyethane by measurements at 9.345μ where the olefinic reactant absorbs only negligibly. Treating the first point taken as a "zero point" the data on five other points between 900 and 3300 seconds (23 and 62% reaction) gave first-order rate constants between 2.06 and 3.40 x 10^{-4} $sec.^{-1}$ with no noticeable trend.

Kinetics of the Reactions of 2,2-Dihalo-1,1,1-trihaloethanes with Sodium Methoxide in Methanol.--In a typical run 1.1238 g. (4.65 mmoles) of 2,2-dibromo-1,1,1-trifluoroethane was diluted to 100 ml. with methanolic sodium methoxide at 0°. Each of nine pyrex tubes was filled with 10 ml. of this material, sealed, and placed in a 70.5° bath. One sample was removed almost immediately to serve as a "zero point." It was titrated with standard acid and then with

thorium nitrate solution to determine the fluoride ion concentration.[27] After

(27) I. M. Kolthoff and E. B. Sandell, "Quantitative Inorganic Analysis," 3rd ed., The Macmillan Co., New York, N. Y., 1952, p. 721.

twelve days, when 1.08 moles of fluoride ion had been formed per mole of organic halide originally present, only 4% more methoxide had been used up than fluoride had been formed.[28]

(28) In other runs direct titration with silver nitrate showed that about 4% bromide ion was formed.

Calculation of Rate Constants.--Rate constants calculated from the simple second-order rate equation showed a marked tendency to climb during the individual kinetic runs. This is very probably due to the subsequent reaction of the 2,2-dihalo-1,1-difluoro-1-methoxyethane formed by the addition of methanol to the initial reaction product. This explanation is supported by the observation that for several of the compounds well over one mole of fluoride ion could be liberated per mole of reactant. Separate studies on 2,2-dichloro-1,1-difluoro-1-methoxyethane (Table I) show that in the case of 2,2-dichloro-1,1,1-trifluoroethane this subsequent reaction is somewhat faster than the initial reaction. Since the rigorous calculation of rate constants for consecutive bimolecular reactions with comparable rate constants is not a simple matter[29]

(29) A. A. Frost and R. G. Pearson, "Kinetics and Mechanism," John Wiley and Sons, Inc., New York, 1953, p. 165.

and since highly accurate rate constants are not required in any of the arguments presented in this paper, we have devised an approximate method of calculation.

The transformation of the reactant halide to an intermediate of equal reactivity has the same effect on the rate of consumption of base as maintaining the organic halide concentration constant. Since the reactivity of the intermediate is comparable to that of the reactant in the only case on which we have direct observations, we have assumed it will also be in all of the other cases. The usual second-order rate equation may then be reduced to a first-order equation.

$$k_1 = \frac{2.303}{t} \log ([MeO^-]_o/[MeO^-]_t)$$

where the first-order rate constant k_1 is equal to the total second-order rate constant k_2 multiplied by the organic halide concentration.

The data obtained in one run are shown in Table II. The average first-order rate constant obtained was divided by the organic halide concentration to give the total second-order rate constant, which was transformed to the second-order rate constant for dehydrofluorination (2.69×10^{-6} l. mole^{-1}sec.$^{-1}$) by multiplication by 0.955 since 4.5% of the methoxide ions were found to have been used up by a side reaction to give bromide and/or chloride ions. Titrations showed that at 70.5° about 11% iodide ion was formed in the reaction of the diiodide but that none of the other reactants gave more than 4% bromide and/or chloride ions. At 55° this side reaction consumed rather more of the base, reaching a maximum of 20% with the diiodide. Our method of correcting for the side reaction involves the implicit assumption that it yields only chloride, bromide and/or iodide ions (probably by an S_N2 mechanism). If this assumption is incorrect and fluoride ions are produced, by a dehalogenation

Table II

Reaction of $CF_3CHBrCl$ with MeONa in MeOH at 55.0°[a]

Time, sec.	$[MeO^-]$	$10^7 k_1$ sec.$^{-1}$
351,000	0.03385	1.90
780,000	0.03144	1.80
1,270,800	0.02937	1.64
1,870,200	0.02564	1.84
2,563,200	0.02375	1.64
3,175,200	0.02095	1.71
3,943,800	0.01730	1.87
5,165,100	0.01397	1.84
6,726,200[b]	0.01188	1.79
	Average	1.78 ± 0.08

[a]Initial concentrations of base and organic halide were 0.03618 and 0.06321 M, respectively. [b]At this point the total concentration of bromide and chloride ions was found to be 0.0011 M.

reaction for example,[30] there will be a corresponding error in our rate constants listed in Table I. This error should be a maximum for the diiodo compound, for which it will amount to 25% and 12% at 55 and 70.5°, respectively.

(30) Cf. V. V. Korshak, K. K. Samplavskaya and N. M. Dovol'skaya, J. Gen. Chem. U.S.S.R. (English translation), 20, 2153 (1950).

In order to insure that the organic halide being studied (rather than an intermediate derived from it) was the principal reacting species, we used only data taken before two-thirds of it had reacted. In some cases where a relatively large amount of base was used up in a short time at the beginning of the reaction this was assumed to be due to the presence of a reactive impurity and the first point taken was used as the "zero point."

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